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AIRTIGHTNESS OF SWEDISH RESIDENCES

M.D. Lyberg and C-A Boman

Swedish Insitute for Building Research
Box 785,
S-80129
Gavle, Sweden

SYNOPSIS

Pressurization, or depressurization, of buildings is a tool to assess the airtightness of building envelopes. A common working pressure is 50 Pa, and the airtightness is expressed in terms of the number of air changes per hour at 50 Pa. To compare buildings of different size a more efficient measure is to define a non-dimensional leakage area.

We suggest a method to define and calculate the relative leakage area from pressurization data. The method corrects for calibration errors and the effects of aeromotive and buoyancy forces. It is demonstrated that the pressurization can be carried out at pressures much lower than 50 Pa, it is sufficient to apply pressures in the range from 10 to 20 Pa. The lekage areas predicted agree well with those predicted from tracer gas measurements of the air change rate.

The method has been used to calculate relative leakage areas of 300 Swedish dwellings. A comparison is made of the airtightness of residences of different age.

LIST OF SYMBOLS

A	area of building envelope [m^2]
n	rate of air exchange [h^{-1}]
$n(50)$	rate of air exchange at 50 Pa [h^{-1}]
p	pressure difference [Pa]
q	volumetric air flow rate [m^3/h]
v	air flow speed [m/s]
V	wind speed [m/s]
α	relative leakage area [cm^2/m^2]
$\alpha(4)$	relative leakage area at a pressure difference of 4 Pa [cm^2/m^2]
Δp	pressure correction [Pa]
ΔT	temperature difference [K]

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1. INTRODUCTION

Pressurization, or depressurization, of buildings is a tool to assess the airtightness of building envelopes, for example, to test building designs and, for particular buildings, to evaluate the impact of air infiltration and exfiltration on the thermal balance of the building. Combined with infrared thermography pressurization is also applied to detect leakage sites of building envelopes. When testing building designs, all ventilation slots and openings should be sealed, while this should not be the case when testing to predict infiltration rates.

The pressurization, or depressurization, is usually carried out at a pressure difference across the building envelope sufficiently high to ensure that the effect of aeromotive forces and buoyancy forces can be neglected. A common working pressure difference is 50 Pa and the airtightness is expressed in terms of the number of air changes per hour at 50 Pa. Airtightness norms for whole buildings have been specified in the Building Code of some countries, for example Sweden and Norway.

Building pressurization in most cases requires the use of portable fans mounted on an adjustable frame that can be fitted into a window- or doorframe. This assembly is called a blower-door.

For large buildings, an interesting concept is to use the fans of the ventilation system for pressurization. However, it is then not always possible to achieve a pressure difference of 50 Pa across the building envelope. This may be the case also for leaky houses even if a blower door is used.

Expressing the airtightness in terms of the number of air changes per hour at 50 Pa makes it difficult to compare the airtightness of buildings of different size. It is not self-evident how to normalize with respect to the area of the building envelope.

In this paper we investigate in more detail a method earlier proposed (see ref. 1). Applying this method one can:

1. Use low pressure data to assess the airtightness of building envelopes, and

2. Express the air leakiness in terms of a non-dimensional entity, the relative leakage area, which makes it possible to compare even differently sized buildings.

The data base used in the analysis consists of pressurization- depressurization data from about 300 houses and apartments collected by the indoor climate measurement unit of the Swedish Institute for Building Research.

2. DESCRIPTION OF THE METHOD FOR ANALYSIS

Using building pressurization data to plot the air flow across the building envelope versus the pressure difference, one in general obtains a plot where data points for pressurization and depressurization fall on two slightly convex curves displaced relative to one another (see Fig. 1)

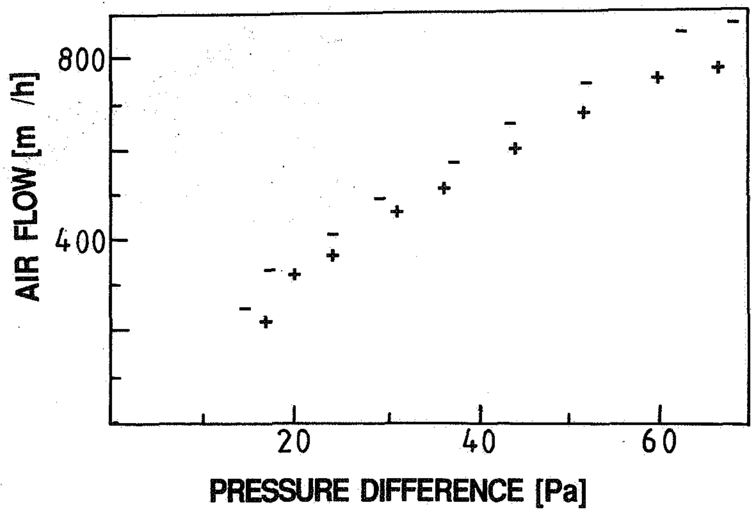


Fig. 1
An example of data points from a pressurization test, air flow versus pressure difference across the building envelope, pressurization (+) and depressurization (-). Note the convexity of the data ponts. Normally, the airtightness of the building envelope is expressed in terms of the number of air changes per hour at a pressure difference of 50 Pa, obtained from the data points by interpolation.

One can then interpolate the pressurization and depressurization curves to a pressure difference of 50 Pa, form the average of the corresponding air flows, and express this average in terms of air changes per hour of the building. Extrapolation of the curves in the plot to pressure differences occuring in real life, rarely above 10 Pa, is difficult because of:

1. The curvature of the data, and
2. The influence of aeromotive and buoyancy forces, and other factors.

It is possible to calculate theoretically a correction, Δp, to the pressure difference measured, p, that compensates for aeromotive and buoyancy forces. This is not of much practical use as one has to consider also factors such as windows and doors moving slightly inwards or outwards with changing pressures, the onset of threshold effects for flows in cracks and, perhaps the most important source of error, the placement of the outdoor pressure gauge which affects the calibration. All these factors are responsible for the displacement of the pressurization and depressurization curves, and their exact impact on data collected is not known. Therefore, instead of a theoretical determination of the pressure correction, Δp, one has to determine the magnitude of the correction from data.

What is required is an approach that can compensate for the above factors by bringing the pressurization and depressurization curves on top of one another and, at the same time, take away most of the curvature to facilitate extrapolations to low pressures. The air flow rate through openings should, for relevant flow regimes, grow as the pressure difference raised to some power, the power taking a value between one half and one. This has been confirmed by field tests to be true also for pressurization data from buildings, even if there is no reason a priori why this should be so due to the complexity of the air flows across building envelopes.

To take away most of the curvature, we use instead of the variables pressure difference, p, and air flow rate, q, a new set of variables, the flow speed, v, defined from

$$v=\sqrt{(2p/\rho)},$$

ρ being the air density, and the variable α, the relative leakage area, defined from

$$\alpha=q/(vA),$$

where A is the area of the building envelope.

The variable v has the dimension of velocity and is a measure of the average flow speed across the building envelope, while α is a dimensionless variable describing the effective cross-sectional area of cracks and holes per square meter of the building envelope.

Suppose we have originally two sets of data points, (p^+, q^+) and (p^-, q^-), where the upper indices + and - refer to pressurization and depressurization data, respectively (as in Fig. 1). Now apply the following procedure:

Construct data sets in the new pair of variables v and α, (v,α), by first replacing the pressures p^+ and p^- by $(p^+ + \Delta p)$ and $(p^- - \Delta p)$, respectively, where Δp is the pressure compensation whose value is to be determined. Defining the corresponding flow speeds:

$$v^+ = \surd[2(p^+ + \Delta p)/\varrho] \text{ and } v^- = \surd[2(p^+ + \Delta p)/\varrho]$$

the new data set is now given by the points:

$$(v,\alpha) = \begin{cases} (v^+, q^+/(A*v^+) & \text{for pressurization data} \\ (v^-, q^-/(A*v^-) & \text{for depressurization data.} \end{cases}$$

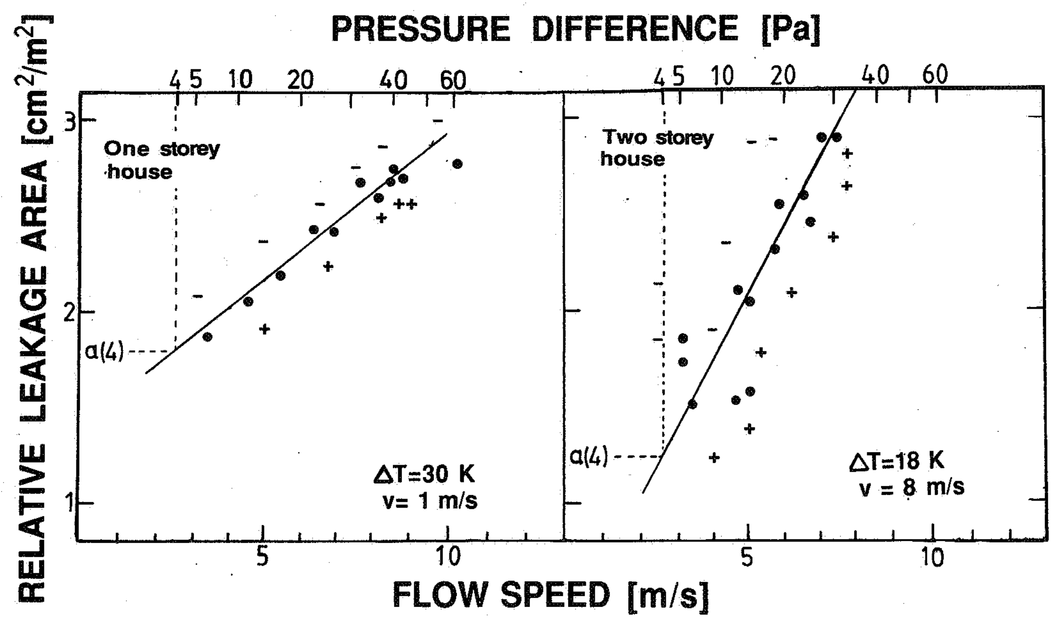


Fig. 2
Measured data points from pressurization (+) and depressurization (-) for two houses, one (left) where the pressure is dominated by aeromotive forces (the wind speed, v= 8 m/s), and another (right) where the pressure is dominated by stack effects (the indoor- outdoor temperature difference is 30 K). The data points have been plotted in the two variables, flow speed and relative leakage area, by the method described in this paper. The resulting data points are given as circles. The straight lines are those giving the best fit to the circles. The hatched lines indicate the extrapolation to obtain α(4), the leakage area at a standardized pressure difference of 4 Pa.

All those data pairs are now to be regarded as belonging to one common data set (see Fig. 2). The pressure correction Δp, which may be positive or negative, is now chosen so that it maximizes the value of the linear regression coefficient if a linear fit to <u>all</u> (pressurization <u>and</u> depressurization) data points in the (v,α) plot is carried out for different values of Δp. This step brings the pressurization and depressurization data together. In most cases, the pressure correction Δp takes a value of a few Pa, or less.

One can now choose a reference pressure (or flow speed), read off the corresponding value of the relative leakage area by interpolation or extrapolation of the straight line in the (v,α) plot, and use this value to characterize the air leakiness of the building envelope. One may use a value of 4 Pa (corresponding to a flow speed of 2.5 m/s) as reference pressure (see ref. 2), a pressure roughly corresponding to the average pressure across the building envelope for external temperatures and wind speeds normal to many climatic regions. We will denote the leakage area at 4 Pa by α(4) and the air exchange rate per hour at 50 Pa by n(50).

When does the above procedure not work? Out of 300 tested cases this method worked in all but two cases. For an example see Fig. 3.

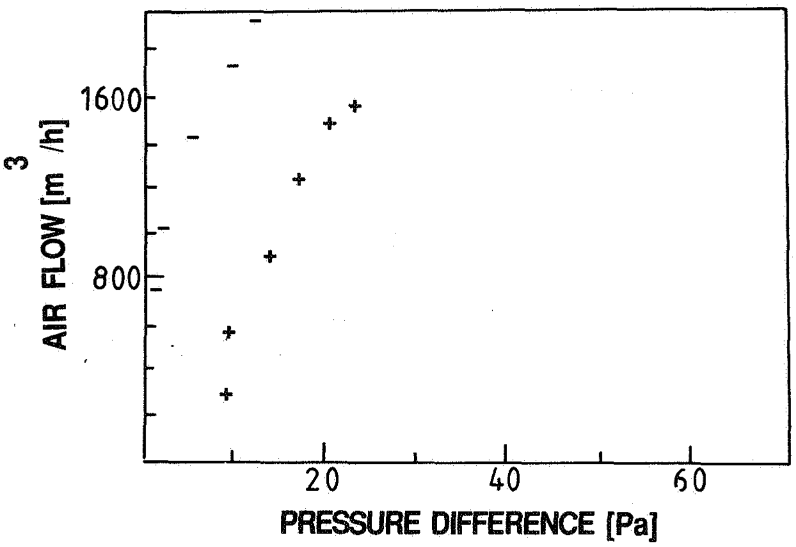
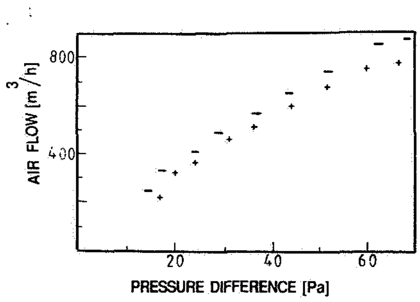


Fig. 3
Pressurization (+) and depressurization (-) data from one of the two cases out 300 for which the method described did not work. Data are from a very leaky house, using an ordinary blower door it was not possible to attain a pressure difference of more than about 20 Pa.

The method desribed above is shortly illustrated in Fig. 4.



1. **Take data pairs (pressure p and air flow rate q) for pressurization (+) and depressurization (-).**

2. **Transform to the new variables**

flow speed $v = \sqrt{(2p/\rho)}$
relative leakage area $\alpha = q/(vA)$

where ρ is the air density and A the building envelope area

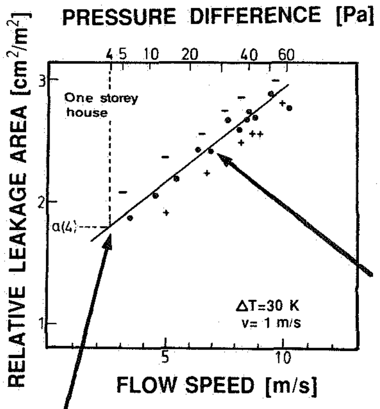
By defining the flow speeds

$v^+ = \sqrt{(2(p^+ + \Delta p)/\rho)}$ **and**
$v^- = \sqrt{(2(p^- - \Delta p)/\rho)}$

where Δp is a pressure correction, obtain new data pairs.

$$(v,\alpha) = \begin{cases} (v^+, q^+/(v^+A)) & \text{for pressurization} \\ (v^-, q^-/(v^-A)) & \text{for depressurization} \end{cases}$$

points



3. **Choose the pressure correction Δp so that it maximizes the linear regression coefficient in a linear regression of all data points, pressurization as well as depressurization data ●.**

4. **Extrapolate the one, from the regression resulting, best fitted straight line to a pressure of 4 Pa to obtain the relative leakage area $\alpha(4)$ at the standardized pressure 4 Pa.**

Fig. 4
Overview of the method described in this paper for the derivation of the relative leakage area.

3. APPLICATION OF THE METHOD

To determine if the method described in the previous section can be used in practice, there are some questions that have to be answered (for a more thorough error analysis, see ref. 3):

1. What is the correlation between the relative leakage area at 4 Pa, α(4), and the rate of air change at 50 Pa, n(50)?
2. Does the method yield the same result if low pressure data, say pressures in the range 10 to 20 Pa, are used instead of pressures in the more normal range 20 to 70 Pa?

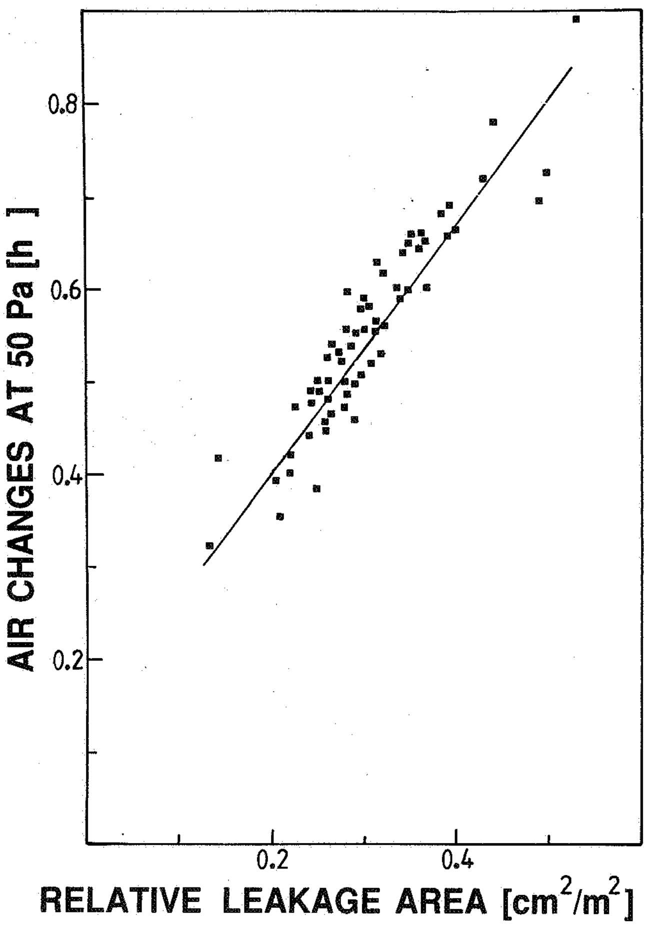


Fig. 5
The measure normally used for evaluating the airtightness of building envelopes, the number of air changes per hour at a pressure difference of 50 Pa, versus the relative leakage area at 4 Pa. The data are from a group of nominally identical townhouses. The square of the linear regression coefficient takes a value of about 0.9.

To answer the first question, we have studied a group of nominally identical two-storey townhouses. The air flow rate n(50) has been plotted versus the relative leakage area $\alpha(4)$ in Fig. 5 for all the houses in the group. The data are from measurements where all ventilation slots and openings had been sealed.

To provide an answer to the second question, we have used data on houses and apartments where there are available data points in the range from 10 to 70 Pa. We have compared the resulting value of the leakage area $\alpha(4)$ when all data points in the range 10 to 70 Pa have been used <u>to</u> the resulting value of $\alpha(4)$ when only data in the ranges 10 to 20 Pa, 10 to 30 Pa and 20 to 30 Pa, respectively, have been used.

The data are displayed in Fig. 6. The average number of data points available for the determination of $\alpha(4)$ in the low pressure range was four. Only data sets from houses containing at least three data points in the respective low pressure range have been used.

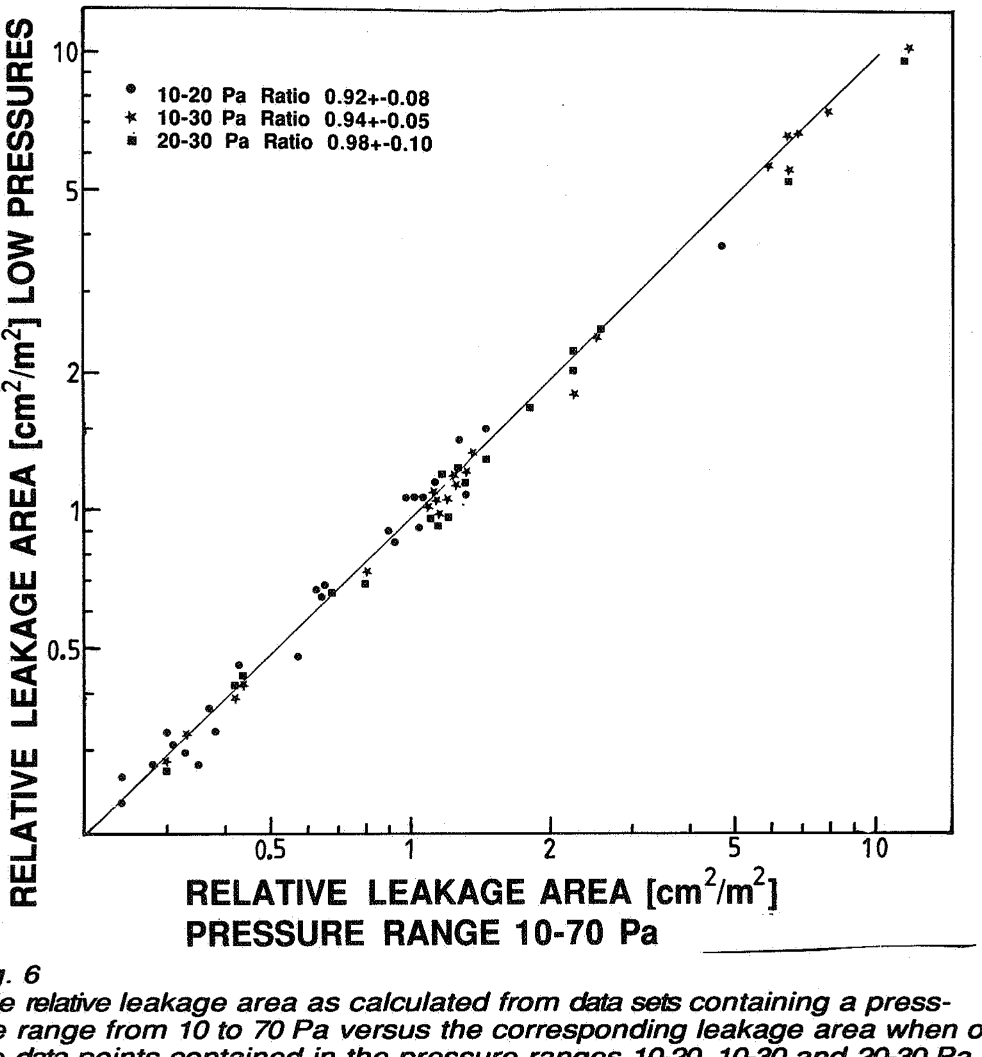


Fig. 6
The relative leakage area as calculated from data sets containing a pressure range from 10 to 70 Pa versus the corresponding leakage area when only the data points contained in the pressure ranges 10-20, 10-30 and 20-30 Pa, respectively, have been used. Also given is the ratio and the standard deviation of the ratio (leakage area from low pressures)/ (leakage area for the range 10 to 70 Pa). All ratios are compatible with being equal to one. Data are from houses, townhouses and apartments.

The resulting ratio of the value of $\alpha(4)$ using low pressure data to the value obtained using the full pressure range is, also, given in Fig. 6. There is an indication that low pressure data may yield somewhat lower values of $\alpha(4)$ than data in the pressure range 20 to 70 Pa, even if all ratios are compatible with being equal to 1.0. The data span more than one order of magnitude of the relative leakage area.

One can then conclude that it should be possible to use just low pressure data to determine a relative leakage area at a pressure difference of 4 Pa serving as an indicator of airtightness of buildings.

To assess if the method can be applied to detect differences in airtightness even for very airtight buildings, the relative leakage area has been calculated from pressurization data for a group of 44 identical townhouses. The data are displayed in Fig. 7. In this case, all inlets and outlets of the houses have been sealed.

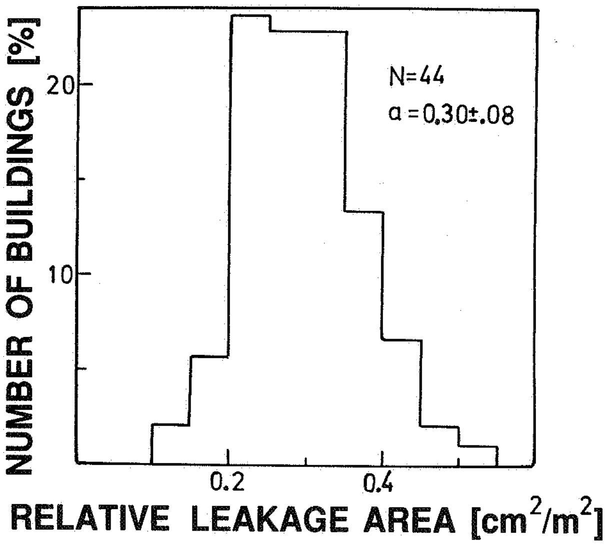


Fig. 7
Distribution of the airtightness in terms of the relative leakage area at 4 Pa for a group of 44 , nominally identical, townhouses. The standard deviation is 25 %, indicating the difficulty to obtain a uniform quality of the airtightness of building envelopes even for identical houses.

The leakage area obtained from pressurization data and the method described above can be compared to the leakage area for the same buildings derived from tracer gas measurements of the air change rate (see ref. 1).

The result of this comparison is displayed in Fig. 8. In this case, all air inlets and outlets of the buildings had not been sealed. There is a fairly good agreement, the standard deviation of the ratio of (the leakage area predicted from pressurization) to (the leakage area predicted from the air change rate) is about 15 %.

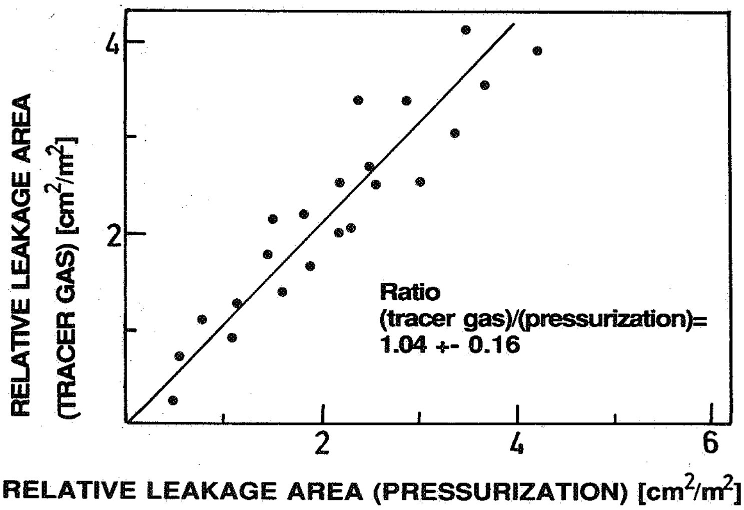


Fig. 8
The value of the relative leakage area as obtained from tracer gas measurements of the air change rate (see ref. 1) versus the relative leakage area for the same buildings as obtained using the method described in this paper. The data are for measurements when air inlets and outlets were not sealed. The ratio (leakage area from air change rate data)/ (leakage area from pressurization data is compatible with being equal to 1, the standard deviation is about 15 % of the average ratio of 1.04.

Using a data set of pressurization measurements from 300 Swedish residences, we have calculated the average relative leakage area (all ventilation openings sealed) for Swedish houses of different age. In Fig. 9 this is compared to measured values of the air change rate for houses of the same age (ventilation openings not sealed). For air change rates, the fall-off with the year of construction is less dramatic than it is for the relative leakage areas.

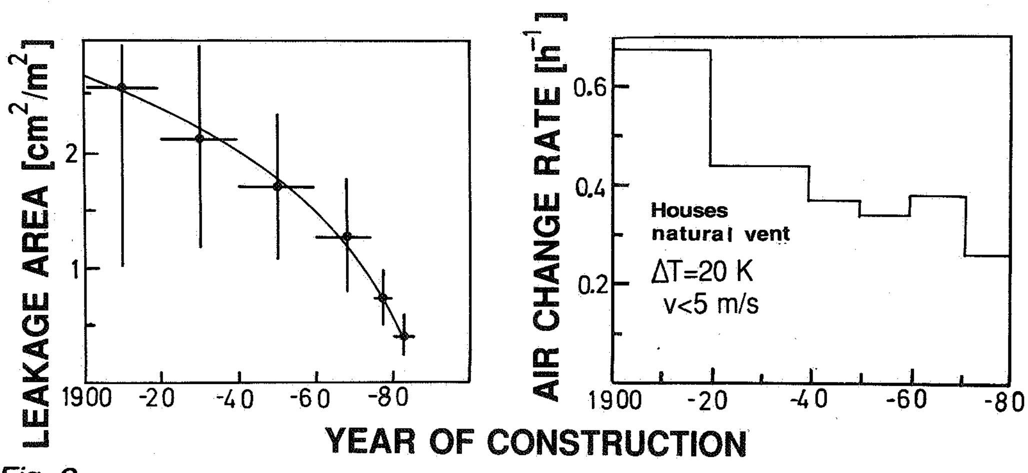


Fig. 9
The airtightness, expressed in the relative leakage area at 4 Pa, of Swedish houses with sealed ventilation slots and openings (left) and the average rate of air exchange for Swedish houses with natural ventilation (right) constructed this century. The air change rate has been corrected to an indoor- outdoor temperature difference of 20 K and measurements carried out at wind speeds exceeding 5 m/s have not been considered.

4. CONCLUSIONS

We have described a method for the calculation of the relative leakage area of buildings using data on air flow rate and pressure difference from pressurization tests. As an indicator of the airtightness of building envelopes, one can use the relative leakage area at a pressure difference of 4 Pa. The value of the leakage area is obtained from a plot where the original data on the variables air flow and pressure difference have been replaced by a new pair of variables.

There is a good correlation between the relative leakage area at 4 Pa and the rate of air exchange at a pressure difference of 50 Pa.

The method yields approximately the same value of the relative leakage area whether low pressure data from 10 to 20 Pa or pressure differences in the range from 10 to 70 Pa are used. The method has previously been shown to give a value of the relative leakage area that is close to the value deduced by measuring the rate of air exchange using tracer gas techniques (1).

To confirm that the method described can be put to practical use, the method should be verified by pressurization tests on more building types. One should also carry out several pressurization tests on the same building using low pressures to better estimate the error of the method.

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